

## National Assessment of Oil and Gas

# Assessment of Undiscovered Oil and Gas Resources in the Paradox Basin Province, Utah, Colorado, New Mexico, and Arizona, 2011

Using a geology-based assessment methodology, the U.S. Geological Survey estimated means of 560 million barrels of undiscovered oil, 12,701 billion cubic feet of undiscovered natural gas, and 490 million barrels of undiscovered natural gas liquids in the Paradox Basin of Utah, Colorado, New Mexico, and Arizona.

## Introduction

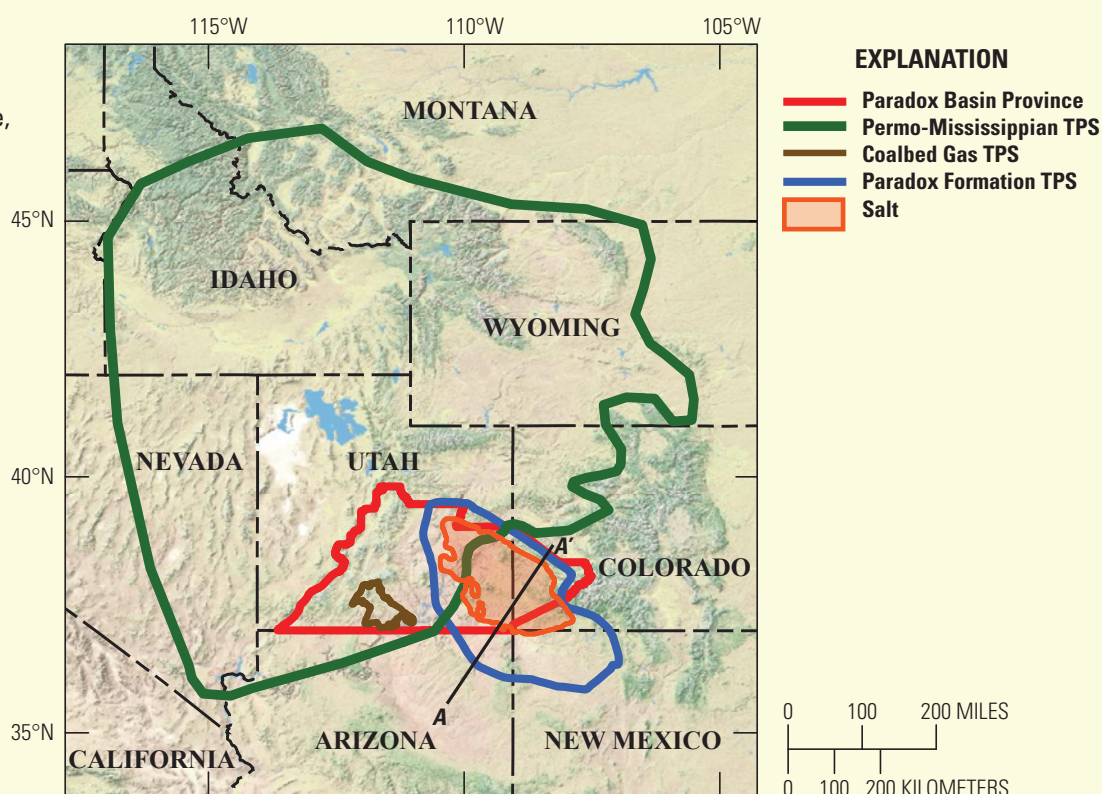
The U.S. Geological Survey (USGS) recently completed a geology-based assessment of the undiscovered, technically recoverable oil and gas resources in the Paradox Basin, which extends into parts of Utah, Colorado, Arizona, and New Mexico (fig. 1). Figure 1 shows the Paradox Basin Province boundary, as defined by Gautier and others (1996), as part of the 1995 USGS National Assessment. The assessment was based on the geologic elements that define a total petroleum system (TPS), which include petroleum source rocks (source rock maturation, petroleum generation and migration), reservoir description (reservoir presence and quality), and petroleum traps (trap type, timing of trap formation, and timing of seal deposition). Using this framework, seven TPSs were identified in the Paradox Basin. Four conventional assessment units (AU), four

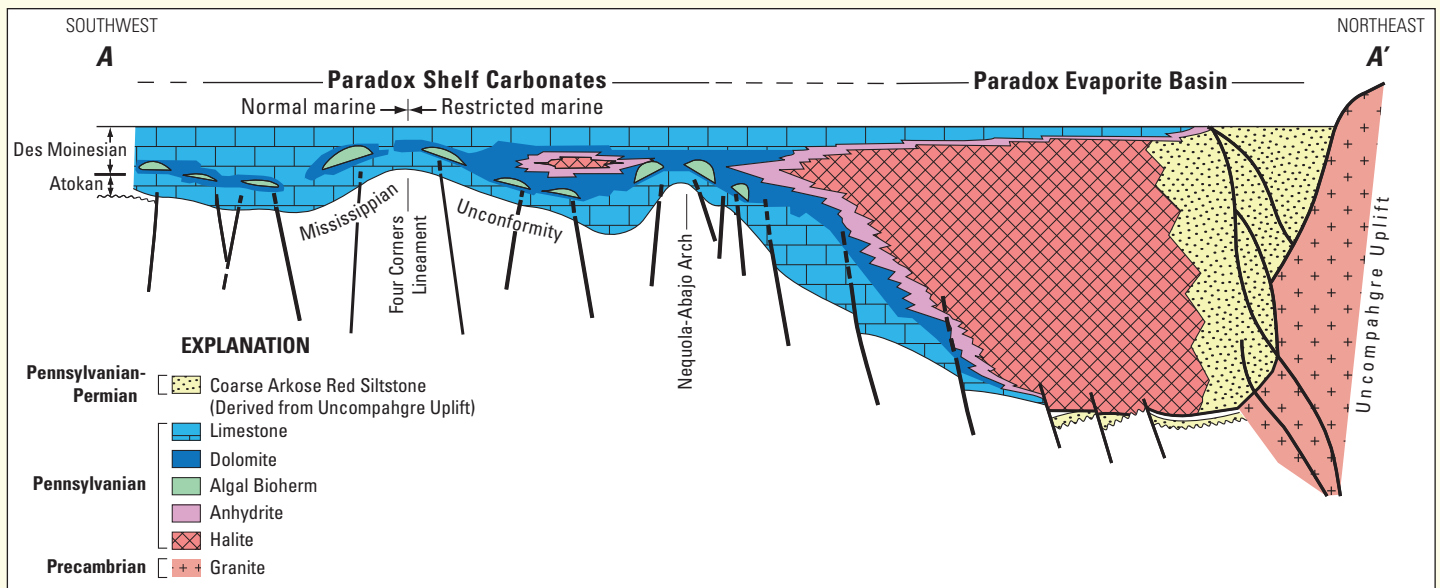
continuous AUs, and one coalbed gas AU were quantitatively assessed.

## Geologic Summary

The Paradox Basin formed in the Pennsylvanian as a response to large intraplate stresses that have been attributed to the collision of Gondwana and Laurentia (Barbeau, 2003; Kluth and DuChene, 2009). The basin is asymmetric, with the deepest part along the north margin, adjacent to the Uncompahgre uplift in Utah and Colorado (fig. 2). Interbedded salt and black shales were deposited close to the north basin margin, along with clastics shed off the Uncompahgre uplift. Penesaline and normal marine carbonates developed along the gently dipping southwest basin margin and interfingered with the salt and black shales.

**Figure 1.** Location of Paradox Basin with the Permo-Mississippian, Coalbed Methane, and Paradox Formation Total Petroleum System (TPS) boundaries and the Paradox Basin Province boundary. The orange polygon delineates the boundary of salt deposition. Hypothetical assessment units not shown on map.





**Figure 2.** Northeast to southwest cross-section of the Paradox Basin (modified from Goldhammer and others, 1991).

### Paradox Formation Total Petroleum System

The Paradox Formation TPS (fig. 1) is defined by hydrocarbons sourced from Middle Pennsylvanian (Desmoinesian) black dolomitic shales of the Paradox Formation that were deposited in the subsiding basin (fig. 2). These shales are interbedded with thick salt deposits. Petroleum from these source rocks is present in three conventional AUs (fig. 3a): (1) Leadville McCracken; (2) Pennsylvanian Carbonate Buildups and Fractured Limestone, and (3) Upper Paleozoic – Mesozoic Reservoirs. Conventional accumulations are defined as those that have well-defined boundaries and hydrocarbon-water contacts, and tend to have adequate porosity and permeability.

The Leadville McCracken AU consists of Mississippian limestones and Devonian sandstones that are interpreted to have undergone hydrothermal fluid flow since the Oligocene (Chidsey and others, 2009), which created localized reservoir-quality porosity and permeability. Migration of hydrocarbons from the overlying Paradox Formation was along through-going faults. The Pennsylvanian Carbonate Buildups and Fractured Limestone AU consists of phylloid algal mounds that developed along topographic highs on the shallow southwest flank of the Paradox Basin, with micritic open-marine limestones deposited in the intervening lows and farther basinward. Phylloid algal mounds possess excellent reservoir properties; furthermore, tectonic fracturing, produced from the movement of underlying salt, may have enhanced porosity and permeability in the micritic limestones. The source and reservoir facies are in close stratigraphic juxtaposition, and short-distance lateral and vertical migration was along faults and fractures. Traps are mainly stratigraphic, controlled by porosity and permeability trends in the algal mound facies and by fracturing due to salt movement. Seals are provided by overlying tight dolomite facies. The Upper Paleozoic–Mesozoic Reservoirs AU contains stacked reservoirs of mixed continental, lacustrine, and fluvial clastic rocks of Late Pennsylvanian through Jurassic age. Hydrocarbons sourced from the Paradox Formation likely migrated into overlying reservoirs through vertical faults and extensive

fracture networks that are associated with salt structures. Traps are provided by salt anticlines, ridges and walls, and nonreservoir quality units (intraformational and interformational) act as seals.

Four unconventional AUs also were defined as part of the Paradox Formation TPS (fig. 3b): (1) Cane Creek Shale Oil AU; (2) Cane Creek Shale Gas AU; (3) Gothic, Chimney Rock, Hovenweep Shale Oil AU; and (4) Gothic, Chimney Rock, Hovenweep Shale Gas AU. Continuous reservoirs are defined as those with diffuse boundaries and lacking obvious traps and seals. Production from these reservoirs is typically enhanced or controlled by fractures. The Cane Creek Shale Oil and Shale Gas AUs and the Gothic, Chimney Rock, Hovenweep Shale Oil and Shale Gas AUs are differentiated by a maturation boundary of vitrinite reflectance = 1.1 percent, with the more mature strata (gas) in the deeper part of the basin near the Uncompahgre uplift.

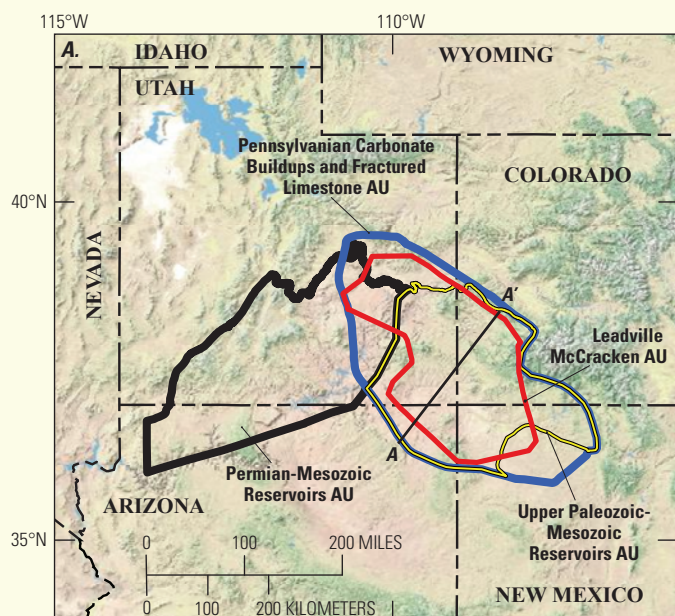
### Permo-Mississippian Total Petroleum System

The Permo-Mississippian TPS (fig. 1) is defined by the presence of oils from either the Permian Phosphoria Formation or the Mississippian Delle Phosphatic Member of Chainman Shale and equivalents, or both. Geochemical data support the interpretation that the oils originated from the Phosphoria Formation, but do not exclude their origin from the Delle. The Permian–Mesozoic Reservoirs AU (fig. 3a) includes many of the same clastic reservoirs as the Upper Paleozoic–Mesozoic Reservoirs AU, but these reservoirs contain Permo-Mississippian TPS hydrocarbons. The Manning Canyon Continuous Gas AU was not quantitatively assessed.

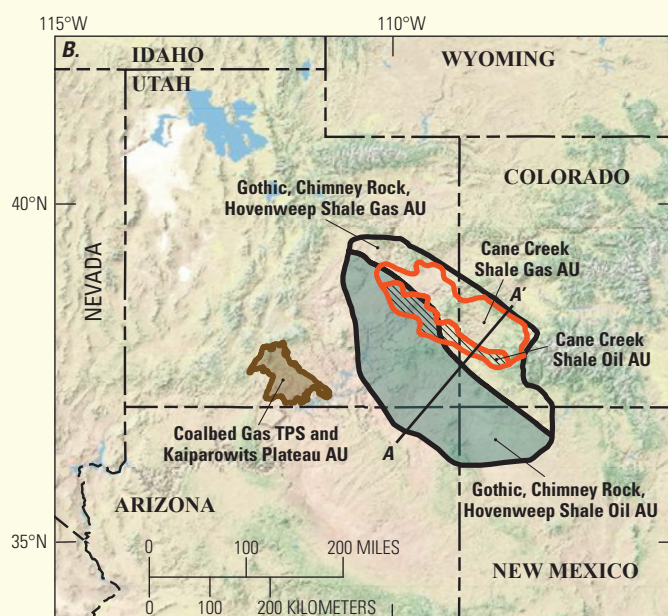
### Coalbed Gas Total Petroleum System

The Coalbed Gas TPS is in the south-central part of Utah (fig. 1). The Kaiparowits Plateau AU (fig. 3b) was assessed for coalbed methane from the Upper Cretaceous Straight Cliffs Formation. The Henry Mountains Coalbed Gas AU was not quantitatively assessed.





**Figure 3a.** Location of four conventional assessment units (AUs) in the Paradox Basin.



**Figure 3b.** Location of five continuous assessment units (AUs) in the Paradox Basin. TPS, total petroleum system.

### Hypothetical Total Petroleum Systems

Two TPSs were recognized in the Paradox Basin that do not have any known resources and could not be quantitatively assessed. The Precambrian Chuar Group contains shales with up to 10 percent total organic carbon that could have generated technically recoverable hydrocarbons within the Precambrian Chuar Self-Sourced Reservoirs AU. The Devonian Aneth Formation is described as having black shale intervals and because the Devonian is one of the major source rock intervals worldwide (Klemme and Ulmishek, 1991), the formation is recognized as having some potential for technically recoverable hydrocarbons within the Devonian Self-Sourced Reservoirs AU.

### Resource Summary

The USGS assessed undiscovered, technically recoverable oil and gas resources in nine assessment units in the Paradox Basin (table 1). Four conventional AUs were assessed to contain means of 89 million barrels of oil (MMBO), 833 billion cubic feet of gas (BCFG), and 18 million barrels of natural gas liquids (MMBNGL). Four unconventional AUs were assessed to contain means of 471 MMBO, 11,868 BCFG, and 472 MMBNGL. The Kaiparowits Plateau Coalbed Gas AU was assessed to contain a mean of 450 BCFG. The assessment was based on 2011 IHS well and production data (IHS Energy Group, 2011).

### For Further Information

Supporting studies of the geologic models and the methodology used in the 2011 Paradox Basin assessment are in progress. Assessment results are available at the USGS Central Energy Resources Science Center website: <http://energy.cr.usgs.gov/oilgas/noga/>.

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## Assessment Team

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**Table 1.** Paradox Basin Province assessment results.

[MMBO, million barrels of oil; BCFG, billion cubic feet of gas; MMBNGL, million barrels of natural gas liquids. Results shown are fully risked estimates. For gas accumulations, all liquids are included as NGL (natural gas liquids). F95 represents a 95-percent chance of at least the amount tabulated; other fractiles are defined similarly. Fractiles are additive under the assumption of perfect positive correlation. TPS, total petroleum system; AU, assessment unit. Gray shading indicates not applicable]

Total petroleum systems (TPS) and assessment units (AU)	Field type	Total undiscovered resources											
		Oil (MMBO)				Gas (BCFG)				NGL (MMBGL)			
		F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
Paradox Formation TPS													
Leadville McCracken AU	Oil	6	19	39	20	16	54	124	60	2	7	17	8
	Gas					16	47	105	52	0	0	1	1
Pennsylvanian Carbonate Buildups and Fractured Limestone AU	Oil	15	51	102	54	21	74	162	81	2	6	14	6
	Gas					147	509	987	530	0	1	1	1
Upper Paleozoic-Mesozoic Reservoirs AU	Oil	2	4	10	5	6	17	41	20	0	1	2	1
	Gas					27	81	164	87	0	1	2	1
Permo-Mississippian TPS													
Permian-Mesozoic Reservoirs AU	Oil	2	9	25	10	1	2	8	3	0	0	0	0
	Gas					0	0	0	0	0	0	0	0
Total conventional resources		25	83	176	89	234	784	1,591	833	4	16	37	18
Paradox Formation TPS													
Cane Creek Shale Oil AU	Oil	103	198	382	215	84	175	364	193	6	14	31	15
Cane Creek Shale Gas AU	Gas					2,473	4,284	7,420	4,530	88	168	319	181
Gothic, Chimney Rock, Hovenweep Shale Oil AU	Oil	126	238	449	256	91	186	382	205	7	15	32	16
Gothic, Chimney Rock, Hovenweep Shale Gas AU	Gas					3,342	6,075	11,042	6,490	120	238	472	260
Precambrian Chuar Group TPS													
Precambrian Chuar Self-Sourced Reservoirs AU	Oil	Not quantitatively assessed											
Devonian TPS													
Devonian Self-Sourced Reservoirs AU	Oil	Not quantitatively assessed											
Permo-Mississippian TPS													
Manning Canyon Continuous Gas AU	Gas	Not quantitatively assessed											
Coalbed Gas TPS													
Kaiparowits Plateau Coalbed Gas AU	Gas					205	411	824	450	0	0	0	0
Henry Mountains Coalbed Gas AU	Gas	Not quantitatively assessed											
Total continuous resources		229	436	831	471	6,195	11,131	20,032	11,868	221	435	854	472
Total undiscovered oil and gas resources													
		254	519	1,007	560	6,429	11,915	21,623	12,701	225	451	891	490